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APPLICATION FOR UNITED STATES LETTERS PATENT

TITLE: TORQUE SIGNAL TRANSMISSION

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Title: Torque Signal Transmission

FIELD OF THE INVENTION

This invention is concerned with a method of and apparatus for the sensing of torque and the transmission of a torque-dependent signal to a remote measurement apparatus by a wireless technique. In this content, wireless transmission means signal transmission without the need of a cable or other like physical connection.

The invention finds particular utility in a torque-generating system in which the torque is generated as pulses of torque. An example of such pulse torque generation is in power fastening tools for fastening or tightening nuts onto bolts or studs for example. Power fastening tools find application in many industries, a major one of which is automobile assembly.

BACKGROUND TO THE INVENTION

The measurement of torque applied to a fastening, such as a nut and bolt, has long presented problems in determining the point at which a desired torque value is achieved when using pulse-type power torque tools. Among the techniques developed for measuring pulsed torque are those based on magnetic transducer technology in which a magnetised transducer is incorporated in or coupled to a torque transmission shaft in a power tool and a torque-dependent magnetic field component is sensed by a non-contact sensor arrangement to develop a torque-representing signal which is transmitted by an electrical connection to signal-processing circuit. The complete torque measuring assembly can be mounted in the tool. An alternative is to transmit a torque-dependent signal from the tool to a remote signal processing circuit as by a cable or wire connection. Even if the signal

were to be transmitted by a wireless connection, e.g. an infra-red link, it is necessary to provide power to the tool end of the link.

There would be considerable benefit in a torque sensor with remote signalling to a processor which did not require electrical power to be provided in association with the sensor. A torque sensor of this kind would be of particular value applied in a power torque tool adaptor of the kind described in British patent application GB 0219745.7 filed 23rd August 2002 which is incorporated herein by reference and to which further reference will be made below.

The application of magnetic transducer technology for torque measurement in a power impact tool is disclosed in U.S. patent 6 311 786 and in its published continuation application US 2002/0020538 in which torque measurement and control is contained within the tool. The torque transducer uses a ferromagnetic sensor and specifically discloses a magneto-elastic ring coupled to the output shaft of the tool. An impact tool control method and apparatus is described in International patent application publication WO01/44776. The control system uses a magneto-elastic torque transducer mounted exteriorly of the tool in which the magneto-elastic transducer element is an integral portion of a shaft through which torque is transmitted. This document also discloses the implementation of the control system as a retrofit system for use in controlling an existing impact tool. The magnetic field generated by the transducer element is detected by a detector which can be a coil of wire circumferentially arranged around the transducer or other device. The coil is connected into the input of an integrator in a signal processing circuit.

The PCT patent application PCT/EP02/06960 filed 24th June 2002, the disclosure of which is incorporated herein by reference, discloses the control of a pulsed torque tool using a magnetic-based torque transducer which has a

transducer element or region integral with the output shaft of the tool. The control apparatus including the transducer is disposed interiorly of the power torque tool.

Above-mentioned application GB 0219745.7 describes an adaptor attachable to a conventional power torque tool of the pulsed-type whereby torque measurement and control can be exercised on the tool. In GB 0219745.7 the adaptor is connected to a unit containing external circuitry by a cable. It may be coupled by a wire-less link, e.g. an IR link, to transmit a torque-dependent signal to the external unit but in that case, the adaptor requires electrical power for its operation.

SUMMARY OF THE INVENTION

One aspect of the present invention is based on the concept of transmitting a torque-dependent signal to a remote unit by means of an emanated field. In particular it is applied to modify an adaptor of the kind described in GB 0219745.7 so that the adaptor is active in the sense of being magnetically active to generate the torque-dependent signal but is passive in the sense of not requiring a source of electrical power.

Another aspect of the invention is based on the concept of deriving an electrical power supply from torque pulses to power a signalling system for transmission to a remote unit and, if appropriate, to power a sensor arrangement.

Aspects and features of the present invention are set forth in the claims following this description.

The invention and its practice will be further described with reference to an embodiment illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an adaptor for fitting to a power torque tool to transmit a torque-dependent signal in accord with the present invention;

Fig. 2 illustrates the internal construction of an adaptor based on that disclosed in GB 0219745.7

Fig. 3 shows a shaft with an integral magnetised transducer region and a sensor coil;

Fig. 4 is a response curve as a function of the axial position of the sensor coil for a transducer region having profile-shift longitudinal magnetisation;

Fig. 5 shows the connection of the arrangement of Fig. 3 with a power supply and signal transmission circuit, all energised by sensed torque pulses;

Fig. 6 shows a modification of the arrangement of Fig. 3 to use a capacitative load;

Fig. 6a shows the circuit used to investigate the "resonance" effect of a capacitative load;

Figs. 7a to 7c are response curves to pulse torques of lower, medium and higher torque respectively using the circuit of Fig. 6a;

Fig. 8 shows a simplified illustration of a torque adapator to which a coil sensor is applied;

Fig. 9 is a preferred coil arrangement for use with the response curve of Fig. 4 and

Fig. 9a is the preferred connection of the two coil sections of the coil arrangement of Fig. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows a conventional power torque tool 10, such as an impact-type fastening tool which provides torque pulses at an output shaft 12. The tool may also be of the type in which pulses are generated by controlled actuation of a piston and cylinder mechanism. The tool illustrated is powered by compressed air through line 14. It is conventional to fit a load-engaging adaptor on the end 12a of the shaft 12 distal the power tool for transmitting torque to the load, e.g. a nut or bolt head. Such an adaptor is exemplified in PCT/EP02/06960. The adaptor is a passive mechanical article for transmitting torque from the shaft to the load. As above-mentioned in the system described in PCT/EP02/06960, torque measurement and control is performed within the tool body 10.

In the illustrated embodiment of the present invention a torque sensor adaptor 20 is provided to enable torque measurement and control to be exercised on a conventional pulsed torque tool not containing such provision. The adaptor 20 couples to the tool output shaft at one end and receives a conventional passive adaptor for engaging a load at the other end. The adaptor incorporates a torque transducer arrangement using a magnetic-based torque transducer element. The adaptor 20 can be characterised as an active device in contrast to prior passive devices. However, as will become clear hereinafter, the adaptor is magnetically active as regards torque sensing but is passive in the sense of requiring no electrical power supply for operation. The adaptor 20 emanates a field carrying a torque-dependent signal as indicated by arrow 50 which is received by a remote receiver unit 52. Unit 52 is connected by cable connection 22 to a signal processing and controller unit 30 which in turn supplies a shut-off signal over cable connection 32 to an air-valve unit 40 acting in line 14. The unit 30 may include a display 34, e.g. an LCD display, for displaying relevant parameters on a manually actuable key pad 36 for entering control instructions and data to a programmed

microprocessor (not shown) housed in unit 30. The unit 30 can be mounted or carried so as to be free of the vibration generated in operation of the tool 10. The receiver unit 52 may be included within unit 30. As schematically illustrated by chain lines 24 the adaptor 20 has a body portion 26 which is securable or attachable to the body of the power tool 10 as will be described below. The adaptor has a torque transmitting shaft extending through the body and having an output end 28.

Fig. 2 shows one form of construction for the adaptor 20 which is constructed to transmit torque about an axis A-A. It is a general aim of the construction to keep the axial length of the torque transmitting shaft as short as possible. The adaptor has a housing 26 with an internal circular bore 27 in which is mounted a torque transmitting transducer assembly 60 rotatable within the housing 26 about central axis A-A.

The assembly 60 has a shaft portion 62 disposed between an input portion 64 and an output portion 66 providing the output end 28 of Fig. 1. The input and output roles are reversible but the shaft portions 62 and 64 are shaped in accord with usual power tool practice. The input portion 64 is configured for engagement with the shaft 12 of tool 10. It is of larger diameter than the shaft portion 62 and includes an axial blind bore 68 configured to fit on the distal end 12a of the tool output shaft 12. For example, if the tool output shaft is of a square cross-section, the bore 68 is of a matching square section. The output portion 66 is shown in this embodiment as a square cross-section shaft similar to the output shaft 12 of the power tool and to which a passive load-engaging adaptor can be fitted. It will be understood that the input and output portions of the assembly 60 can be configured as required by the tool and the load adaptor respectively; or the output portion 66 could be configured for direct engagement with the load.

The shaft portion 62 is of circular cross-section and is radially-spaced from the adjacent inner surface of housing 26. Shaft portion 62 is magnetised at 70 to provide a torque-sensitive transducer element or region which emanates a torque-dependent magnetic field which is sensed by a sensor arrangement to be described and not shown in Fig. 2.

The region 70 is a region of stored magnetisation. That is, it is remanently magnetised to store a permanent magnetisation. Preferably the magnetisation is an annulus of longitudinal magnetisation about axis A-A. the longitudinal magnetisation is in the direction of axis A-A, e.g. as illustrated N-S. The longitudinal magnetisation may be of the kind known as circumferential sensing as disclosed in WO01/13081 or, preferably, of the kind known as profile-shift (axial or radial sensing) as disclosed in WO01/79801. Another torque measuring technique which does not require a region of stored magnetisation is that disclosed in British patent application GB 0204213.3 filed 22nd February, 2002. In this technique the transducer element is not a previously magnetised or (encoded) region of the shaft but is a defined region in which the torque-sensitive element is established in use.

Looking at further details of the constructions of the adaptor of Fig. 2, the output portion of square cross section includes recess 65 for co-operating with a standard passive mechanical adaptor. The transducer region 62 is located for rotation within the housing by a plain bearing provided by an annular bush 80 of a plastics material which is bonded to or otherwise secured against rotation to a forward (i.e. toward the output end) inside surface 27a of the housing 26. The interior diameter of bush 80 is slightly greater than the diameter of region 62, other than for a forward lip 82 which bears against the shaft.

The rearward end of bush 80 seats against an internal step 27b of housing 26 and also provides an abutment 84 for axially locating the transducer assembly

and specifically a forward surface of the enlarged input portion 64. The input portion is sized to rotate freely within a part 26a of the housing of reduced internal diameter extending from step 27b to a rearward internal step 27c. Step 27c lies adjacent a circumferential groove 67 in the input portion 64. An annular bushing 86 of a low friction, self-lubricating material is received in the groove and engages the interior surface of housing 26 and is axially located by step 27c. The bushing 86, and therewith the transducer assembly 60 is retained in the housing by an internally-located press-fit retaining ring 88 at the rear of the housing. The housing 26 not only provides mechanical support and protection but provides a magnetic shield for the transducer assembly. It will be understood that the construction illustrated in Fig. 2 is diagrammatic in nature.

One feature of the assembly 60 of Fig. 2 is that the input portion 64 terminates at 64a flush with the rearward end 26b of the housing 26 or within the axial confines of the housing which is in accord with the desire to keep the overall length of the active adaptor as small as possible. The square-section bore 68 for engaging the output shaft of the power tool is contained within the housing. The assembly 60 is a push fit into the housing 26 from its rearward end.

To perform the function generally indicated at 24 in Fig. 1 of preventing rotation of the adaptor housing and to retain the output shaft 12a of the power tool engaged within the bore 68, the exterior of housing 26 is adapted to retain one end of a stiff helical spring (or more than one such spring) the other end of which is retained on the housing of the power tool. The spring, thus retained, is in an axially stretched state (in tension) so that the tension maintains the active adaptor engaged with the power tool. It has also been found that the flexibility of the retaining spring enables the power tool fitted with the active adaptor to accommodate the variations in the angle between the torque axis and the load being fastened that occur in practical use of the

tool. It will be understood the plain bearing type of rotary support provided by bush 80 and bushing 86 could be substituted by other means of bearing support.

The description given so far with reference to Figs. 1 and 2 closely follows the description of the adaptor disclosed in GB 0219745.7. Attention will now be given to the modifications to that design by which the present invention is implemented.

Referring to Fig. 1, in GB 0219745.7 the adaptor 20 is connected directly to the processing unit by cable 22. The adaptor houses a magnetic field sensor arrangement co-acting with a transducer region which is connected via cable 22 into a signal conditioning circuit in unit 30; or which is connected to a signal conditioning circuit within the adaptor which circuit then transmits a torque-representing signal to the unit 30 over cable 22. Either way, the operation of the sensor devices in adaptor 20 requires electrical power to be supplied in or to the adaptor. The substitution of a wire-less link, e.g. an infra-red (IR) link, for the cable 22 would still require the supply of power in or to the adaptor. The foregoing disadvantage can be obviated by the torque sensing and signal sending techniques now to be described. The technique is of general utility and is not restricted to being applied to the adaptor under specific consideration.

Fig. 3 shows a ferromagnetic shaft 100 rotatable about a longitudinal axis A-A. An integral portion 70 of the shaft is encoded with a remanent, annular magnetisation of the kind referred to a profile-shift as described in above-mentioned WO01/96826. A single coil is wound closely about the shaft. For the purposes of the immediate discussion the coil is movable axially with respect to the region 70. The coil is terminated in a low value resistor R, of say 270Ω. Fig. 4 shows a graph of the voltage across the resistor (current induced to circulate in the coil) as a function of the axial position of the coil

relative to region 70 when the transducer region is subject to a torque pulse of a given value. Current is induced in the coil by the resultant torque-dependent change in the magnetic flux distribution acting on the coil. M The coil current is proportional to the rate of change of flux during the torque impulse. By way of example, the encoded region 70 may be 22 mm wide and the width of the coil 4-5 mm with the coil having 300 turns or more.

When a torque pulse is applied to one end shaft 100, it propagates along the shaft "winding up" the shaft. There is then a lesser recoil pulse of opposite polarity dependent on the elasticity of the shaft material. This phenomenon will appear in torque pulse graphs described later.

Reverting to Fig. 4 it will be seen that the voltage across resistor R is at a maximum at two points 72a, 72b spaced from the centre-line 74 of the region 70. The polarity reverses as the coil passes through alignment with the centre line and investigation thus far has revealed that the maximum voltages are achieved when the coil is aligned with the sweet spots described in WO01/96826 with reference to Fig. 30 thereof.

The voltage/current induced in the coil 110 has two possible functions. The first is as a source of electrical energy. That is the transducer provides a mechanical(torque)-to-electrical energy converter. The second is as a torque-dependent signal usable in a subsequent torque measurement and control process. Fig. 5 is a diagrammatic illustration of the use of the voltage/current induced in the coil for both possibilities.

In Fig. 5 the coil 110 is connected to a power control unit 112 which generates a supply voltage V_s at terminal 114. The unit 112 may include a rectifier arrangement, connected across the coil to develop a usable power supply voltage from the voltage at the coil terminals. The rectifier arrangement is preferably of the full wave bridge type to use excursions of both polarities of the coil output voltage. The rectifier arrangement feeds a smoothing

capacitor to derive a smoothed unipolar voltage from the rectifier arrangement and a low power voltage regulator device may also be employed. The supply voltage V_S is used to power the torque signal transmission part of the arrangement of Fig. 5.

The torque-dependent signal voltage developed across the coil is applied as the input to a signal conditioning circuit 120 which processes the signal to generate a torque signal V_T which modulates a transmitter unit 122 to transmit the torque-representing signal by any form of wireless connection 50, such as light (visible or otherwise), radio, sound, induction etc.

The coil 110 may be tightly wrapped around the region 70 of shaft 100 at an axial position at which maximum energy output is generated, e.g. a sweet spot as discussed with reference to Fig. 4. Consequently if the coil is to rotate with the shaft and if the shaft is to continue to rotate under successive torque pulses, it may be necessary to connect the coil to the remainder of the circuitry through slip rings. Alternatively the coil 110 may be wound sufficiently spaced from the shaft to allow the shaft to rotate within a fixed coil. The shaft may be a steel of the type mentioned below.

A presently preferred embodiment of the invention will now be described which makes use of remote signalling but does not require the provision of a power supply to energise a transmitter device. This implements the second function mentioned above.

It will be noted that the power generating function of the coil 110 could be used for powering a magnetic field sensor arrangement using sensor devbices such as saturating core inductors, Hall effect devices or magnetoresistive devices. The torque-dependent signal thereby obtained modulates transmitter unit 122 for remote signalling as already described.

Fig. 6 is similar to Fig. 3 but shows a capacitor C connected across the coil 110. The coil may be in the range of 300 to 600 turns on a 15-18 mm diameter shaft of FV 250B steel. Other suitable steels are those known under the designations S155, SI56 and 14 NiCo14. The steels have to be chosen for a combination of the mechanical properties required for the torque transmission system in which they are employed and their magnetic properties for sustaining the transducer region 70 and providing a torque-dependent magnetic field component.

It has been found that such a circuit can produce a resonance which causes the coil 110 to emanate a field 50, which is detectable at some distance away. The resonance may serve to amplify the current generated in the coil. The resonance may be at a harmonic frequency related to the pulse period. The radiated field can be detected with the aid of a receiving coil 130 of say 600 turns wound on a ferrite rod. The signal has, for example, been detected on a long-wave radio using a ferrite rod aerial, that is a radio tuned in the range 150-300 kHz. The emanated field from coil 110 has been detected over a range of 30 cms up to 1.5 m.

This resonance effect has been investigated with the coil circuit shown in Fig. 6a in which the coil 110 is connected to a resonating capacitor C of 1μF in series with a resistor R of 270 Ω. The voltage across the coil is displayed in conjunction with a separate measurement of the torque acting on the transducer region. Figs. 7a, 7b and 7c are graphical displays of the detected signals for lower, medium and higher torque values respectively. The measured torque signal is the upper trace in each case, the voltage V_c across the coil is the lower trace. The coil voltage polarity is inverted which is an artifact of the instrumentation used.

The torque pulse T shows as a positive going portion T+ followed by a negative going portion T- which represents the recoil due to mechanical

energy stored in the shaft by the applied torque. The magnitude of the recoil pulse T- depends on the amount of rotation of the shaft in response to the applied torque and associated energy losses. The "torque pulse" acting on coil 110 is in the form of the torque-dependent magnetic flux generated by the transducer region 70. The coil voltage/current is primarily responsive to the rate of change of flux as already noted, that is the rate of change of the torque pulse T. It should be said that the precise nature of the torque pulse as applied to fastening a nut and bolt when the two are becoming tight is a complex subject.

The coil voltage V_c is in the nature of a double pulse, having two pulses V_1 and V_2 of opposite polarity which relate to the slope of the rising part of the applied torque pulse T and the slope of the relaxation part of the torque pulse respectively. It has been found that for torque pulses, the peak height of the coil signal is proportional to the amount of torque applied during the torque pulse. The steepness of the torque pulse slope is dependent on the initial pulse as generated, e.g. by a power torque tool, the load acting on the shaft and the shaft material, that is the elasticity of the shaft. The voltage V_c across the coil has been found to be in a range of a few to several hundred millivolts which is significant.

The teachings given above for both functions mentioned have related to investigations with the profile-shift form of longitudinal magnetisation described in WO01/96826. However, other magnetisations which produce torque-dependent magnetic fields may be treated in a similar way. Reference has already been made to circumferential-sensing longitudinal magnetisation described in WO01/13081 and circumferential or circular magnetisation in a magneto-elastic material such as disclosed in U.S. patents 5 351 555 and 5 465 627 and SAE Technical Paper Series 920707 published by the Society of Automotive Engineers under the title "Development of a Non-Contact Torque Transducer for Electric Power Steering Systems".

Circumferential magnetisation can also be used in an integral portion of a shaft. As will be decribed below the response obtained with longitudinal magnetisation of the kind described in WO01/96826 and on which the response of Fig. 4 is founded, can be utilised in a particularly beneficial way by using a two-coil sensor.

However, continuing with the single coil sensor so far discussed, its application to the adaptor of Figs. 1 and 2 will now be described. Fig. 8 shows a torque-detecting adaptor for a power torque tool such as illustrated in Fig. 2. The earlier description of Fig. 2 did not describe the sensor arrangement which coacts with transducer region 70. A coil sensor arrangement based on the teachings of Figs. 3 and 4 is shown in Fig. 8 in which the adaptor is shown in simplified form. The housing 26, which may be of enlarged radial thickness, is provided with an external groove in which the coil 110 is seated and retained to sense the field emanated by the region 70 of shaft portion 62 (Fig. 2). The coil 110 is not in contact with the shaft in the adaptor which is free to rotate within the coil. The coil should be positioned axially at a sweet spot 72a or 72b of Fig. 4. For the coil 110 to coact with region 70, the material of housing 26 (and bush 82) should not be of a magnetic material so that the coil is properly influenced by the field emanated by region 70.

An alternative is illustrated in Fig. 2 itself in which the coil indicated as 110' is embedded within the bush 82. The coil can be positioned radially close to transducer region 70 but without actually contacting the region. In order to emanate a field from the coil to communicate with the receiver unit 52 of Fig. 1, the housing 26 should be of a material that does not adversely screen the emanated field. The receiver unit 52 employs a coil wound on a ferrite rod as described with reference to Fig. 6.

To make better use of the response characteristic of Fig. 4, the modification shown in Fig. 9 is preferred. The single coil 110 is substituted by two spaced coils 110a and 110b, each aligned with a respective sweet spot 72a, 72b. The coils are connected as shown in Fig. 9a so that the resultant voltage V_c is the sum of the magnitudes of the respective coil voltages. By way of example, for a region 70 that is 22 mm wide, the sweet spots were found to be 14 to 15 mm apart. The axial centres of coils 110a, 110b were equally spaced apart, each coil being 4-5 mm long. The signal output voltage can be expected to be in the range of 0.5-1V when using 2 x 300 turn coils on a shaft of 15-18 mm diameter of FV 250B steel, the coils being terminated in a resistor R.

In accordance with the earlier discussion it is preferred to place a "resonating" capacitor, or a series CR combination, across the series connected coils as indicated in Fig. 9a. The additional component(s) are part of the adaptor and, for example, could be embedded in bush 82 as well as coils 110a and 110b.

The resultant adaptor is of rugged construction to meet the high vibration environment in which it is used and requires the minimum of components.

One problem arising out of remote signalling is that the magnitude of a received signal will be a function of distance between the transmitter and the receiver unit. The received signal level will be expected to vary as the inverse square of the distance. Thus unless the signal receiver is maintained at a fixed distance at which a calibration can be made, the magnitude of the received signal is not correlated with the torque that is being measured.

A solution to this problem is to provide the transmitted signal with its own internal reference. Fig. 10 illustrates one solution. It shows a dual polarity pulse output such as is seen in Figures 7a-7c (lower trace) representing the coil voltage V_c. One of the pulse pair is clipped to a fixed amplitude, as by a Schottky diode clipper. This is shown on the second pulse of the pair where

the clipping level is indicated at V_L. This provides a reference against which the amplitude of the first pulse of the pair is measurable.

A second solution is to use a signal, other than the torque pulse, that is generated by the torque pulse source. For example, in impact power torque tools it has been noticed that the hammer mechanism generates a signature torque signal which is separate from the desired torque impulses. This is illustrated in Fig. 11 in which the signature signal S of a constant amplitude lies between the torque pulses of varying amplitude. This provides the reference.